ASR Entrainment Focus Group White Paper

Contributors: M. Jensen, P. Kollias, S. Krueger, Y. Liu, A. Vogelmann

Mission Statement

The goal of the ASR Entrainment Focus Group (FG) is to coordinate the use ARM measurements to study the interactions of cloudy and clear air at the cloud-clear air interface and their impacts on cloud life cycle through the development of new retrieval techniques, the application of these techniques to ARM datasets, the analysis of high-resolution large-eddy simulations that resolve the entrainment process, and the subsequent evaluation and improvement of the representation of entrainment processes in low-resolution numerical models, including global climate models.

Motivation

The complex interactions of dynamics, microphysics, and radiation at the cloud scale and their impacts on cloud lifecycles remain not well understood and represent one of the greatest uncertainties in global climate model simulations. One such important cloud-scale process is entrainment and in particular the engulfment of dry environmental air across the cloud-clear interface, which can induce changes to cloud thermodynamic, microphysical and macrophysical properties. Despite it's effects on cloud lifecycles and cloud properties, entrainment and its subsequent mixing processes are poorly understood and challenging to observe. Individual entrainment events typically occur on spatial scales that are too small to resolve using current remote sensing technologies and therefore must be observed with high-sampling-rate aircraft observations, or interpreted via remote sensing in bulk terms using statistical samples of cloud measurements. Even with these approaches, the role of entrainment is often difficult to unravel from other cloud processes that impact the cloud lifecycle.

Objectives

The scientific objectives of the Focus Group include the following:

- Determine the applicability of existing measurement techniques to ARM observations for the estimation of entrainment.
- Coordinate the development of new retrieval techniques for determining entrainment parameters with an emphasis on radar Doppler spectra and multi-instrument approaches.
- Propose and execute coincident aircraft and surface-based remote sensing field campaigns targeting entrainment processes in shallow cumulus clouds.
- Examine the connection between thermodynamic, dynamical, and microphysical properties to understand and parameterize entrainment rate and mixing mechanisms.
- Test and evaluate parcel model techniques for the parameterization of entrainment processes using existing and new datasets.

Approaches

To achieve the objectives of the Entrainment FG, the following research methodologies are proposed:

1) Forward modeling of new (ARRA) remote sensing observations using existing LES results.

In order to better understand the capabilities of new remote sensing observations for use in entrainment studies, and to understand the relationship between observables and quantities important for the study of entrainment processes, output from existing LESs (e.g., BOMEX, RICO) will be used in collaboration with instrument simulator modules. These exercises will help to guide the development of new retrievals of entrainment properties from ARM remote sensing instrumentation.

2) Utilize existing long-term ARM measurements to retrieve cloud and environmental parameters relevant to entrainment.

There are several historical, long-term ARM datasets available in climatologically distinct regimes that should be examined for their suitability to study entrainment and to evaluate different parameterization techniques. Within the Entrainment FG, initial efforts will be aimed towards the Southern Great Plains Central Facility. This location is chosen for the initial focus group efforts due to the variety of cloud types encountered for which entrainment is important (i.e., shallow cumulus, stratocumulus, cumulus rising into stratocumulus, and deep convection) and the number of remote sensing platforms that are available for use in multi-instrument retrieval techniques (including for example, MMCR/KAZR, SACR, Raman Lidar, MPL, Doppler lidar, 6 hourly radiosondes). Geophysical quantities of particular interest will include cloud fraction, cloud boundaries (particularly cloud-top), vertical velocities within cloud, liquid water content, cloud droplet number concentration, drizzle occurrence, and thermodynamic profiles. Dependent on resources and investigator interests, related work may be performed at other ARM deployments such as the TWP, particularly with respect to deeper convective clouds, and the AMF-Azores (and new Azores site), particularly for marine boundary layer clouds.

3) Model (parcel/LES/CRM/SCM) intercomparisons in order to evaluate the robustness of representation of quantities that play important roles, or are impacted by, the entrainment process including the vertical profile of humidity, buoyancy reversal, and CDNC dependencies.

There is a need for strong coupling between modelling and measurements for the understanding of entrainment processes. This link needs to happen on the LES and CRM scales and then upscaled to SCM/GCM applications. The first step in this process is the definition of several easy-to-simulate case studies, whereby the differences inherent in different models and their underlying physics can be evaluated. A set of cases will be chosen from the ARM SGP (and AMF-Azores) dataset in order to facilitate this comparison study. Observations from the ARM SGP (and AMF-Azores) dataset will be used to constrain and evaluate the simulations. This work will be coordinated with the FASTER project and the GCSS Boundary Layer Clouds Working Group.

Specific science issues with regards to modeling efforts are:

a) Model resolution – With higher resolution, models are able to resolve smaller eddies and are able, therefore, to generate a more turbulent flow. At typical CRM resolutions, the flow around convective plumes can often be rather laminar: how does this effect entrainment rates, and at what resolution does the entrainment rate converge?
b) Microphysical parameterizations – The treatment of microphysics is an important part of the proper representation of the entrainment process in models. The timescale for mixing of entrained air can be significant, and largely determines the nature of the mixing process (e.g., homogenous vesus inhomogenous). By including the activation of newly entrained aerosols, for example, the size spectrum is significantly affected. Furthermore, if activation of new aerosols is omitted, superadiabatic drop sizes may occur. Is this an issue in LES of entrainment in two-moment schemes? How does the choice of microphysics (bulk, two-moment, spectral and variations) affect the relationship between entrainment rate and cloud particle size distributions?
Subgrid-scale and numerical diffusion –Together, these represent sub-grid-scale mixing in all numerical models that do not resolve the smallest turbulent eddies (i.e., the Kolmogorov scale). Sub-grid-scale parameterizations would be worth exploring in an intercomparison.

4) Inter-comparison of GCM convective parameterization schemes

A major motivation for research on entrainment processes is the sensitivity of GCM simulations to the representation of entrainment rate in stratocumulus-topped boundary layers, shallow cumulus layers, and deep convection. There is a rich variety of treatments for entrainment in existing parameterizations, from tuning (single bulk-plume scheme), to calculating a spectrum of entrainment rates based on a CAPE-like closure, to including a uniform distribution of entrainment events, to using stochastic entrainment events (Krueger's 1D model, Romps and Kuang's stochastic parcel model). We would look to evaluate these approaches based on comparisons to the observational statistics or to CRM and LES results.

5) Propose and carry-out a coincident aircraft and surface-based remote sensing IOP targeting entrainment processes in shallow cumulus clouds

A targeted field campaign that includes both surface-based remote sensing and coincident aircraft observations with high temporal/spatial resolution sampling will help to make significant progress possible on the understanding of entrainment processes. This campaign must include scanning cloud radar observations and Doppler spectra from vertically pointing radar. Doppler lidar and Raman lidar observations are also necessary components. The RICO and POST field campaigns will provide examples and guidance for aircraft in situ observational strategies. The aircraft portion of the campaign will need high temporal sampling instrumentation and should include the ability to release and remotely sense chaff as it is entrained into clouds.

Milestones (Tentative, to be revised eachyear)

1st year:

- Collection of appropriate CRM/LES output for forward modelling activities (e.g., A. Ackerman, A. Cheng, W. Grabowski, H. Morrison, A. Khain, S. Krueger, FASTER modelling group).
- Forward modelling activities using CRM/LES output (e.g.,McGill group, BNL group).
- Initial analysis of the SGP observational dataset providing estimates of geophysical quantities important for the understanding of entrainment processes. Particular focus on remote determination of cloud droplet number concentration and liquid water content. (e.g.,Turner, Kollias, Jensen, T. Wagner)
- Using this analysis to define case study opportunities for LES/CRM intercomparison.

2nd year

- Define gaps in exisiting SGP and AMF – Azores observations to be addressed in a future field campaign proposal.
- LES/CRM intercomparison study – Identify differences among entrainment processes in various LES/CRM simulations using SGP and AMF-Azores observations as constraint/validation.
- Formulate and propose an entrainment-focused field campaign using the ARM Mobile Facilities

3rd year

- Continue analysis of SGP andAMF-Azores observational dataset. Particular focus topics include:
    - Relative importance of cloud-top and lateral entrainment (SGP)
    - Entrainment/mixing gradients across convective updrafts (SGP)
    - Impacts of mixing on cloud microphysics (SGP)
    - Relative roles of cloud-top radiative cooling and evaporation on buoyancy (AMF-Azores)
    - Droplet sedimentation (AMF-Azores)
    - Boundary layer decoupling via drizzle evaporation (AMF-Azores)
    - Above inversion humidity impacts on cloud lifecycle (AMF-Azores)
- Coupling of LES/CRM with observations to address the same topics as data analysis.
- Use long-term analysis of SGP andAMF-Azores data for constraint on GCM entrainment processes.
- Assuming approval of field campaign proposal, begin its planning.

4th year

- Continue analysis of SGP andAMF-Azores observational dataset. Particular focus topics include:
    - Relative importance of cloud-top and lateral entrainment (SGP)
    - Entrainment/mixing gradients across convective updrafts (SGP)
    - Impacts of mixing on cloud microphysics (SGP)
    - Relative roles of cloud-top radiative cooling and evaporation on buoyancy (AMF-Azores)
    - Droplet sedimentation (AMF-Azores)

- Boundary layer decoupling via drizzle evaporation (AMF-Azores)
- Above inversion humidity impacts on cloud lifecycle (AMF-Azores)

- Coupling of LES/CRM with observations to address the same topics as data analysis.
- Define necessary improvements to model parameterization of entrainment processes.
- Assuming approval, field campaign deployment (dependent on current deployment schedule).

5th year

- Begin analysis of new field campaign observations.
- Test improved representation of entrainment parameterization using observations from field campaign.
- Write research paper(s) to document what we have learned from research activities.